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Headwinds – a story about wind energy

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UNIVERSITY OF THE PACIFIC

The seal of the University of the Pacific is a circular emblem. It features a central torch with a flame, flanked by two olive branches. The words "UNIVERSITY OF THE PACIFIC" are inscribed around the perimeter, and the year "1851" is at the bottom.

Headwinds- a story about wind energy

Scott Larwood, Associate Professor
The University of the Pacific
Mechanical Engineering Department

Muir Collection at Pacific



The screenshot shows a web browser window displaying the University of the Pacific Library website. The browser's address bar shows the URL: www.pacific.edu/Library/Find/Holt-Atherton-Special-Collections.html?utm_source=Link&utm_medium=GoRedir. The website's header features the University of the Pacific logo and navigation links. The main content area is titled "HOLT-ATHERTON SPECIAL COLLECTIONS" and includes a description of the mission, a list of digital collections, and links to search various collections.

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Holt-Atherton Special Coll... x +

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Location, Hours, Contacts

HOLT-ATHERTON SPECIAL COLLECTIONS



The mission of Special Collections is to collect, preserve, and provide access to manuscript collections made up of primary sources that focus on California, American history, and the University of the Pacific, as well as a specialized book collection. The Special Collections department is open to the public and especially welcomes Pacific students to use its unique resources in their research.

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Browse and search digitized primary sources online

Search Manuscript Collections

Search Book Collections

Using our Archives

John Muir Papers
The world's largest collection of Muir documents

Japanese-American Internment Collections
A variety of documents from the internment camps

Brubeck Collection
The archives of jazz legend Dave Brubeck

University Archives
Historic records generated by administration, faculty, staff and students of Pacific

Muir and the wind



Courtesy of TripAdvisor

- “their written language is too difficult for human minds”
- “The sky, too, was changed, and I could detect strange sounds in the winds.” A *Thousand Mile Walk to the Gulf*

Outline

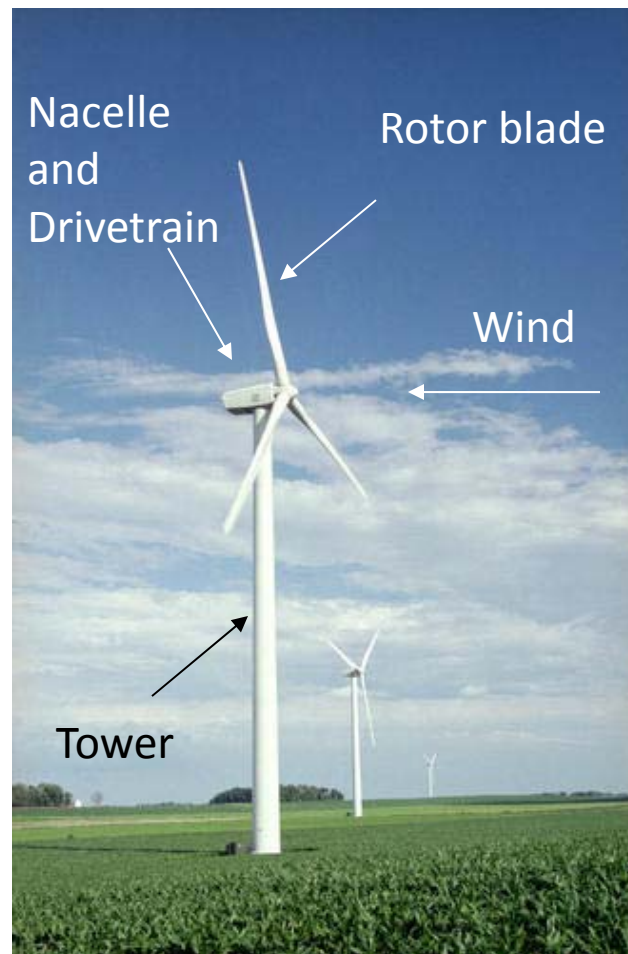


- The present
- First generation
- Second generation
- Third generation
- The future



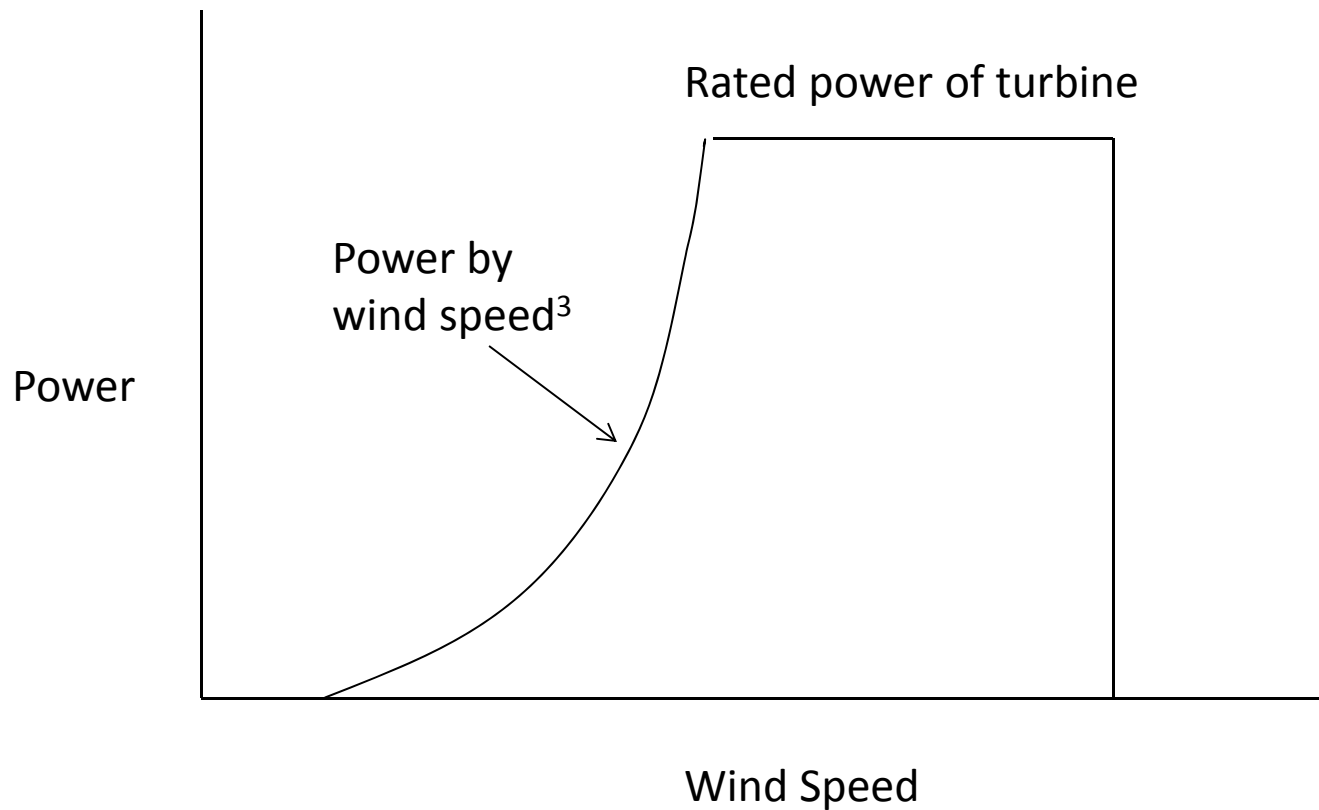
THE PRESENT

The Modern Wind Turbine



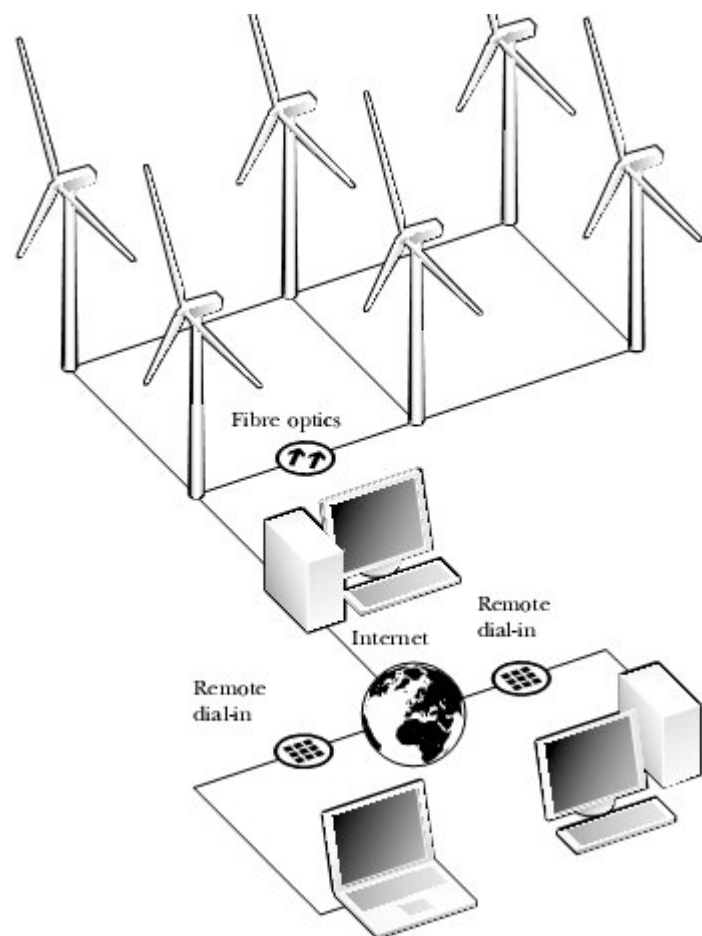
GE 1.5 MW NREL Photo

The Power Curve



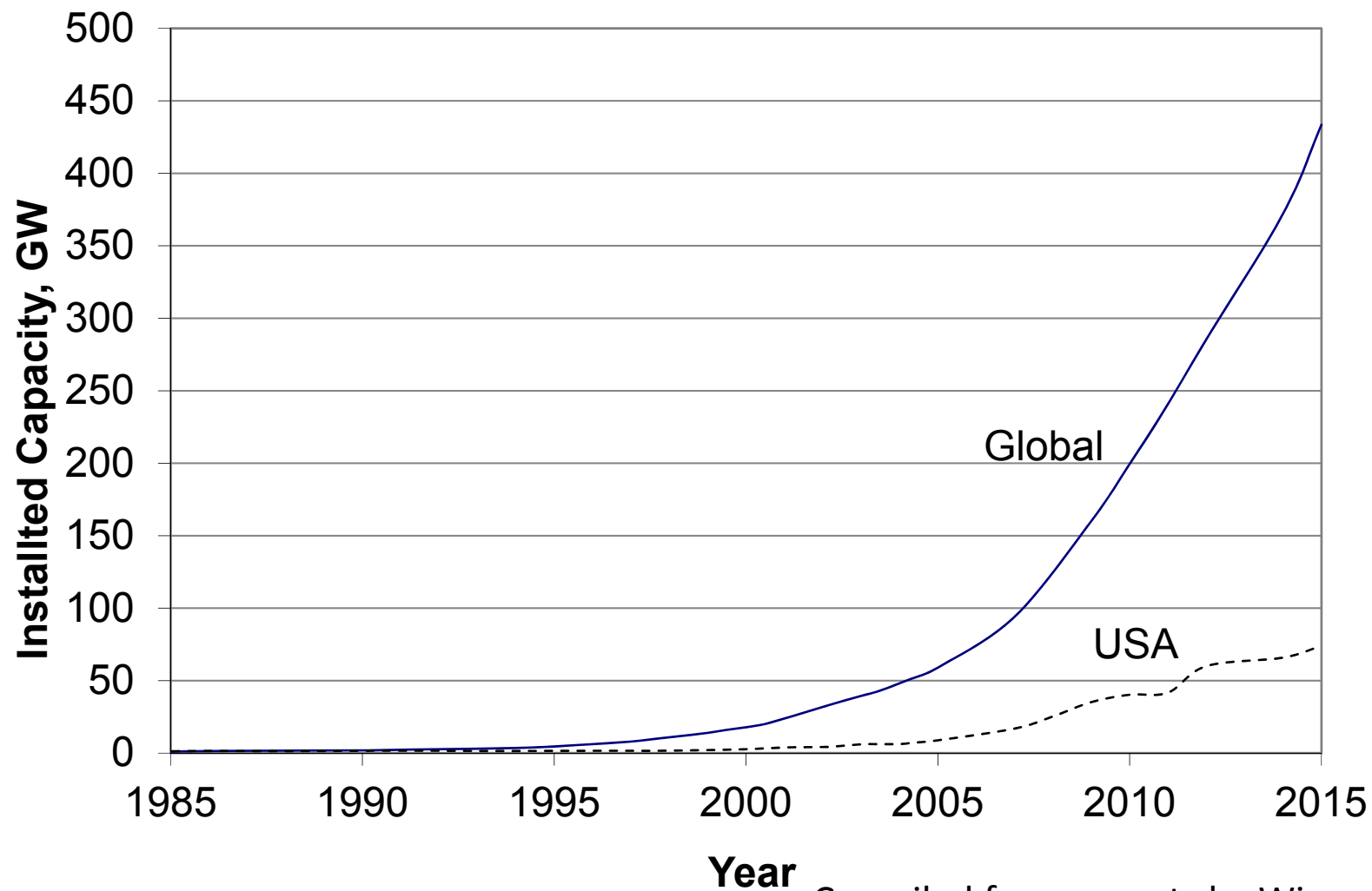
Control of wind energy

- Individual automatic control
- Farm (wind plant) control
- World wide control by manufacturer/owners



Vestas

Growth of Wind Energy



Compiled from reports by Wiser, LBNL

Worldwide capacity

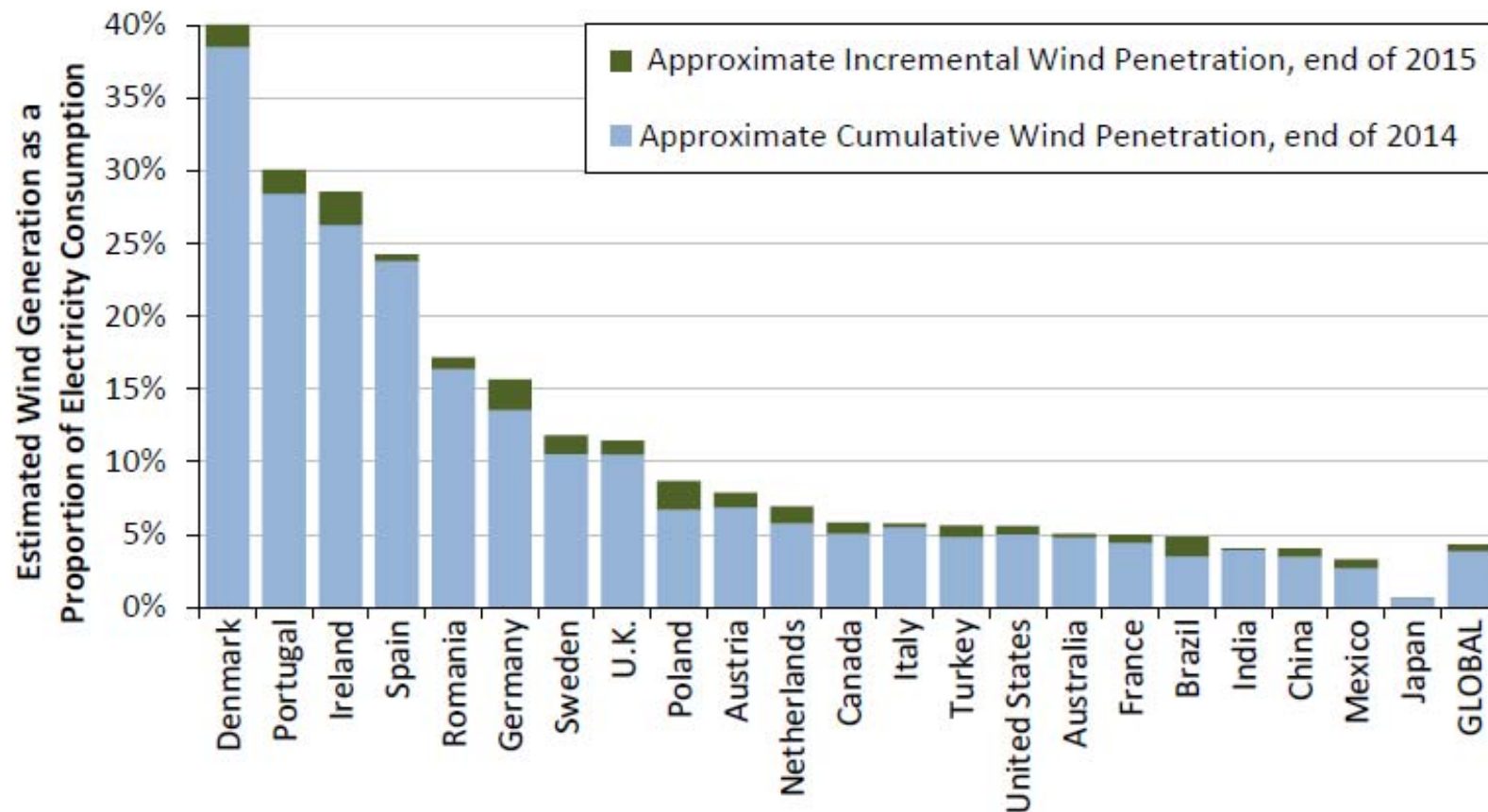


Annual Capacity (2015, MW)		Cumulative Capacity (end of 2015, MW)	
China	30,293	China	145,053
United States	8,598	United States	73,992
Germany	6,013	Germany	44,986
Brazil	2,754	India	25,352
India	2,623	Spain	22,665
Canada	1,506	United Kingdom	13,388
Poland	1,266	Canada	11,190
France	1,073	France	10,243
United Kingdom	975	Brazil	9,346
Turkey	956	Italy	8,851
<i>Rest of World</i>	7,078	<i>Rest of World</i>	68,464
TOTAL	63,135	TOTAL	433,530

Source: Navigant; AWEA project database for U.S. capacity

Wiser 2016

How much energy is from wind?



Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

Wiser 2016

U.S. Wind Energy

Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2015)		Cumulative (end of 2015)		Actual (2015)*	
Texas	3,615	Texas	17,711	Iowa	31.3%
Oklahoma	1,402	Iowa	6,209	South Dakota	25.5%
Kansas	799	California	5,662	Kansas	23.9%
Iowa	524	Oklahoma	5,184	Oklahoma	18.4%
Colorado	399	Illinois	3,842	North Dakota	17.7%
Illinois	274	Kansas	3,764	Minnesota	17.0%
New Mexico	268	Minnesota	3,235	Idaho	16.2%
North Dakota	258	Oregon	3,153	Vermont	15.4%
Minnesota	200	Washington	3,075	Colorado	14.2%
California	194	Colorado	2,965	Oregon	11.3%
South Dakota	175	North Dakota	2,143	Maine	10.5%
Maine	173	Indiana	1,895	Texas	10.0%
Indiana	150	New York	1,749	Nebraska	8.0%
Nebraska	80	Michigan	1,531	Wyoming	7.7%
Arizona	30	Wyoming	1,410	Montana	6.6%
Maryland	30	Pennsylvania	1,340	Washington	6.5%
New Hampshire	14	New Mexico	1,080	New Mexico	6.3%
Ohio	8	South Dakota	977	California	6.2%
Connecticut	5	Idaho	973	Hawaii	6.1%
New York	1	Nebraska	890	Illinois	5.5%
Rest of U.S.	0	Rest of U.S.	5,203	Rest of U.S.	1.0%
TOTAL	8,598	TOTAL	73,992	TOTAL	4.7%

* Based on 2015 wind and total generation by state from EIA's *Electric Power Monthly*.

Source: AWEA project database, EIA

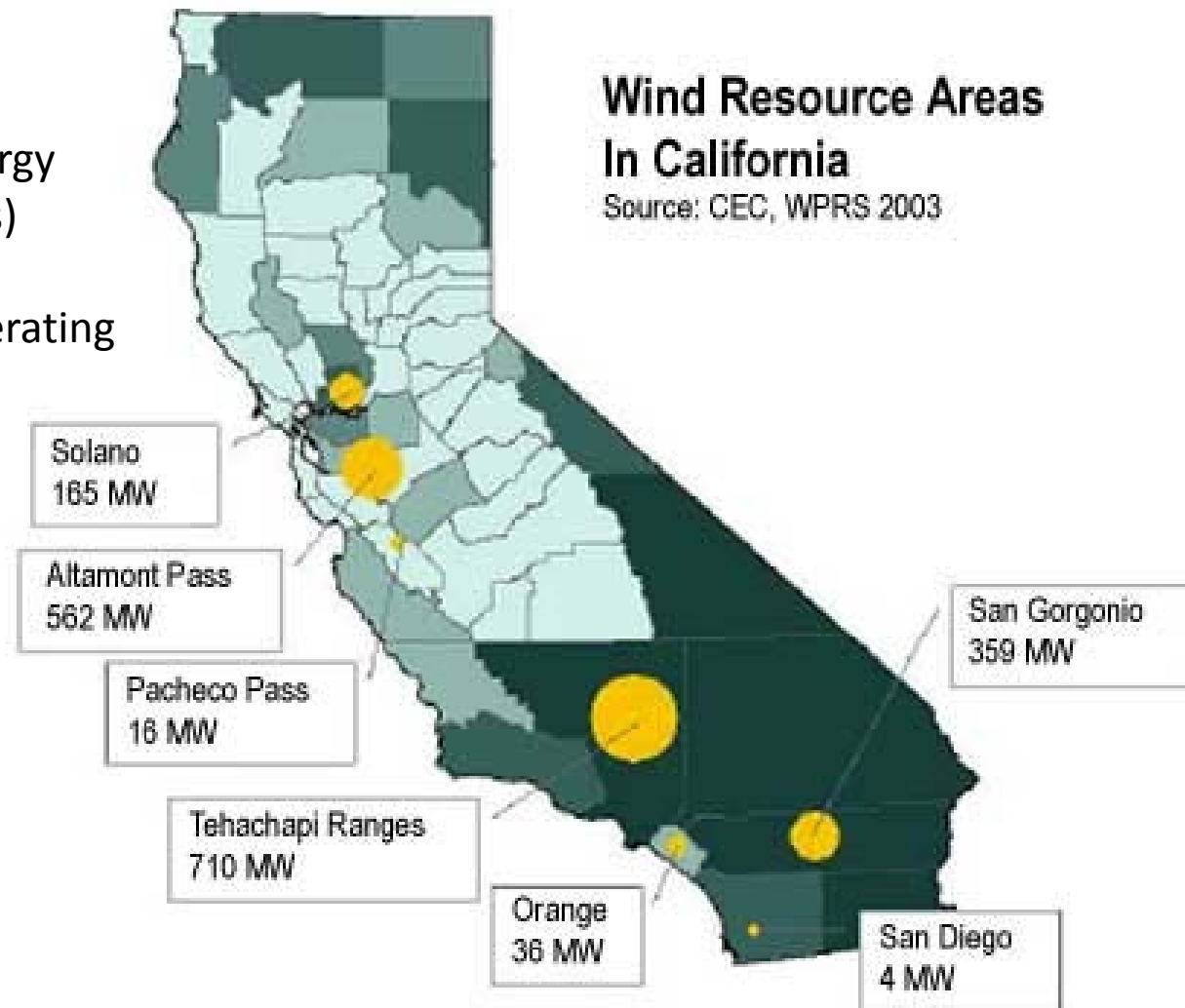
Wiser 2016

California Wind Energy



2015- 5.7 GW
8.2% of total energy
(includes imports)

70 GW total generating
capacity



How efficient is wind energy

- pollev.com/purlwind



FIRST GENERATION

In the Beginning



Energy crises of the 1970s

- 1973 Arab OPEC Embargo
- 1979 Iranian Revolution
- Dependence of energy supply on foreign imports



Remember when?



No cutting please

Department of Energy (DOE) programs



Boeing MOD-2
NASA Photo

- Late 70s early 80s
- Large investment with NASA in aerospace corporate research
- GE, Boeing, Hamilton Standard
- MOD series turbines

Small turbines

- 25 to 100 kW machines
- Univ. of Mass. Wind Furnace
 - Eventually becomes Kenetech Windpower
- Danish firms
 - Vestas, Noordtank, Micon
- Dominate CA wind energy in 80's and 90's



Kenetech turbines- FPL photo



Vestas- Tehachapi CA

My path to wind energy

- Childhood
 - Astronaut!
- Nixon/Carter Years
 - Energy crises
- High school
 - Application to military academies
 - California universities
- Undergraduate
 - Cal Poly – Fall 1984
 - Reagan years



Skylab 4, 1973
NASA Photo

Formative college years

- PG&E internship 1986
- Human-powered helicopter 1985-1989
- Developed interest in low-Reynolds number flows



Boeing MOD-2
NASA Photo



Cal Poly DaVinci III, 1989
William Patterson Photo

Reynolds number

$$\text{Re} = \frac{\rho U_{\infty} L}{\mu}$$

Where:

ρ is the density

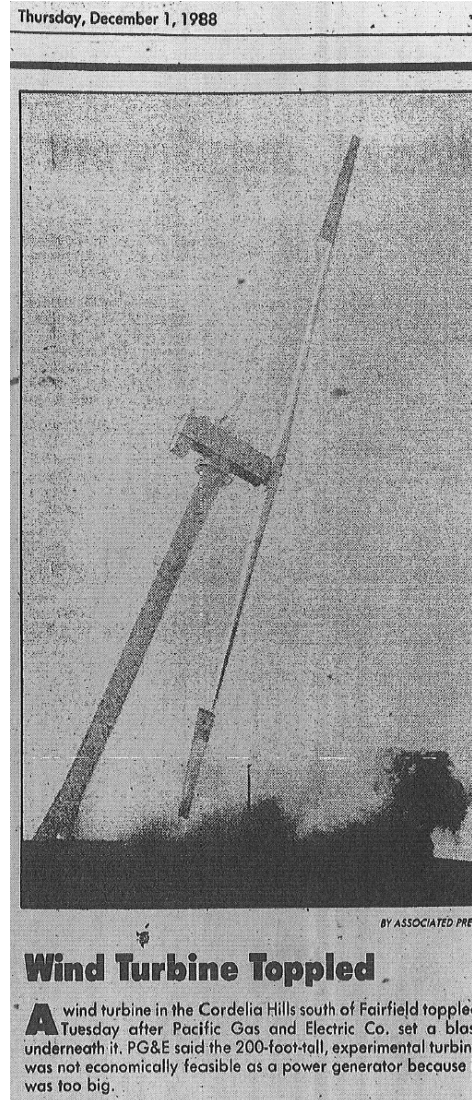
U_{∞} is the velocity

L is a length

μ is viscosity

- Characterizes the flow regime
- Relative from high to low
 - Supersonic jets
 - Passenger jet aircraft
 - Light aircraft
 - Wind turbines
 - Human powered aircraft
 - Insect flight
 - Molasses from a jar

My PG&E MOD experience



Career beginnings

- Graduated Dec 1988
 - 80's Soviet Glasnost
 - 1989 Berlin Wall Falls
- NASA Ames Research Center
 - 1989-1990 Space Life Sciences
 - 1990-1995 Full-Scale Aerodynamics
 - Interest in rotor dynamics
 - Stanford M.S. 1993
 - Aching to work in wind energy



Spacelab in Shuttle Bay
NASA Photo





SECOND GENERATION

Transition to wind energy

- Left NASA for Kenetech Windpower
 - Are you crazy?
 - 1995-1996
- National Renewable Energy Laboratory
 - 1997-2001



Netherlands 1995



Back at NASA with NREL, 2000

Kenetech



American turbines on the
North Sea dike



Not around anymore...

Two-bladed



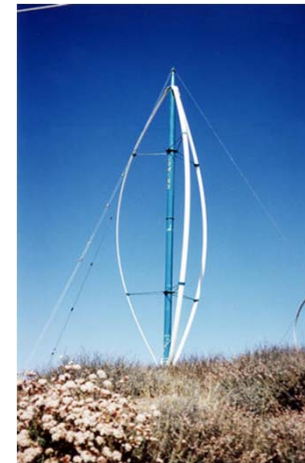
Downwind rotor



Lattice tower



Vertical axis



NREL photos

Avian deaths

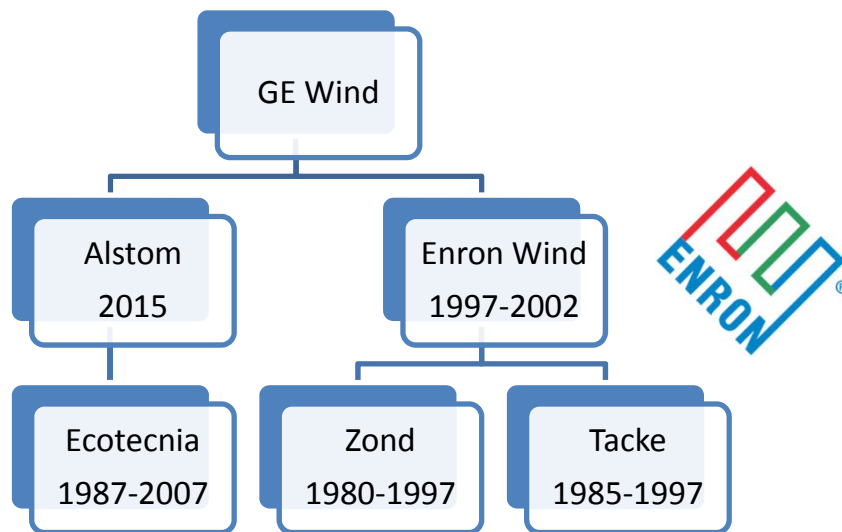


- The Altamont- wind energy's big black eye
- Impact on the wind industry
- Assessment, mitigation, post-monitoring

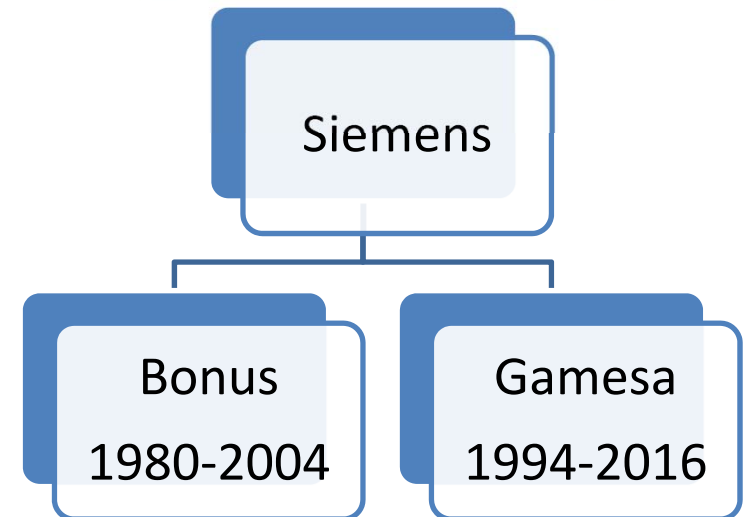


THIRD GENERATION

Big Players



SIEMENS



My times and Enron/GE Wind



GE

Offshore Wind Energy

- 12 GW worldwide at end of 2015 (Wiser 2011)
 - Fastest growing market segment
- Majority in Europe, one plant in US
- Huge European projects in the pipeline
- A few potential East Coast projects on life support

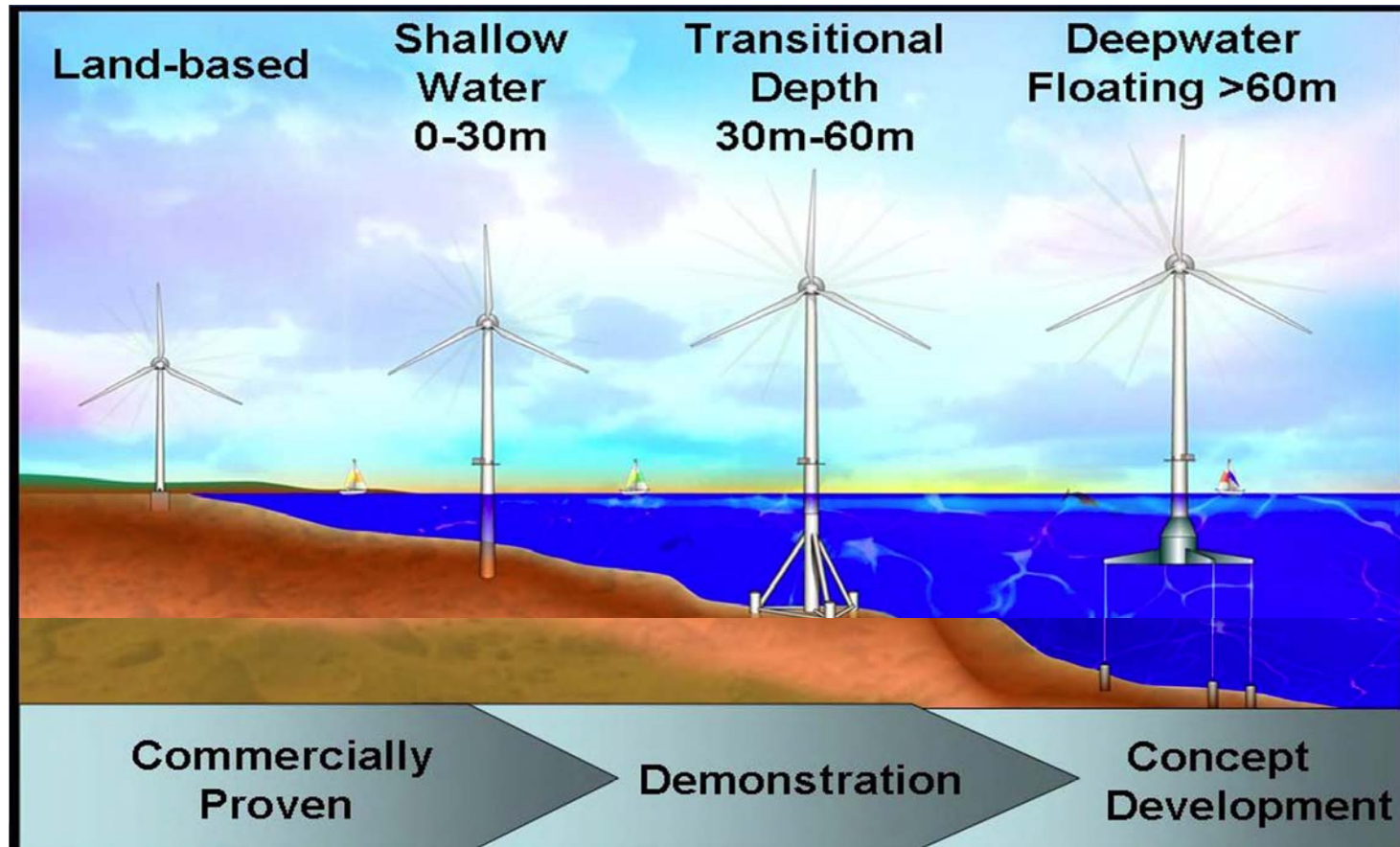


America's First



Deepwater Wind

Primary Offshore Component



NREL

Benefits/Risks of Offshore Wind



- Benefits
 - Offshore winds more consistent and less turbulent
 - Creation of new industries and jobs
 - Revitalization of ports and harbors
- Risks
 - Use conflicts (e.g. cargo transport, fishing, recreation)
 - Wildlife conflicts (e.g. marine animal and birds)
 - Huge up front financial risk (e.g. permitting through several agencies)

Wind energy approval index



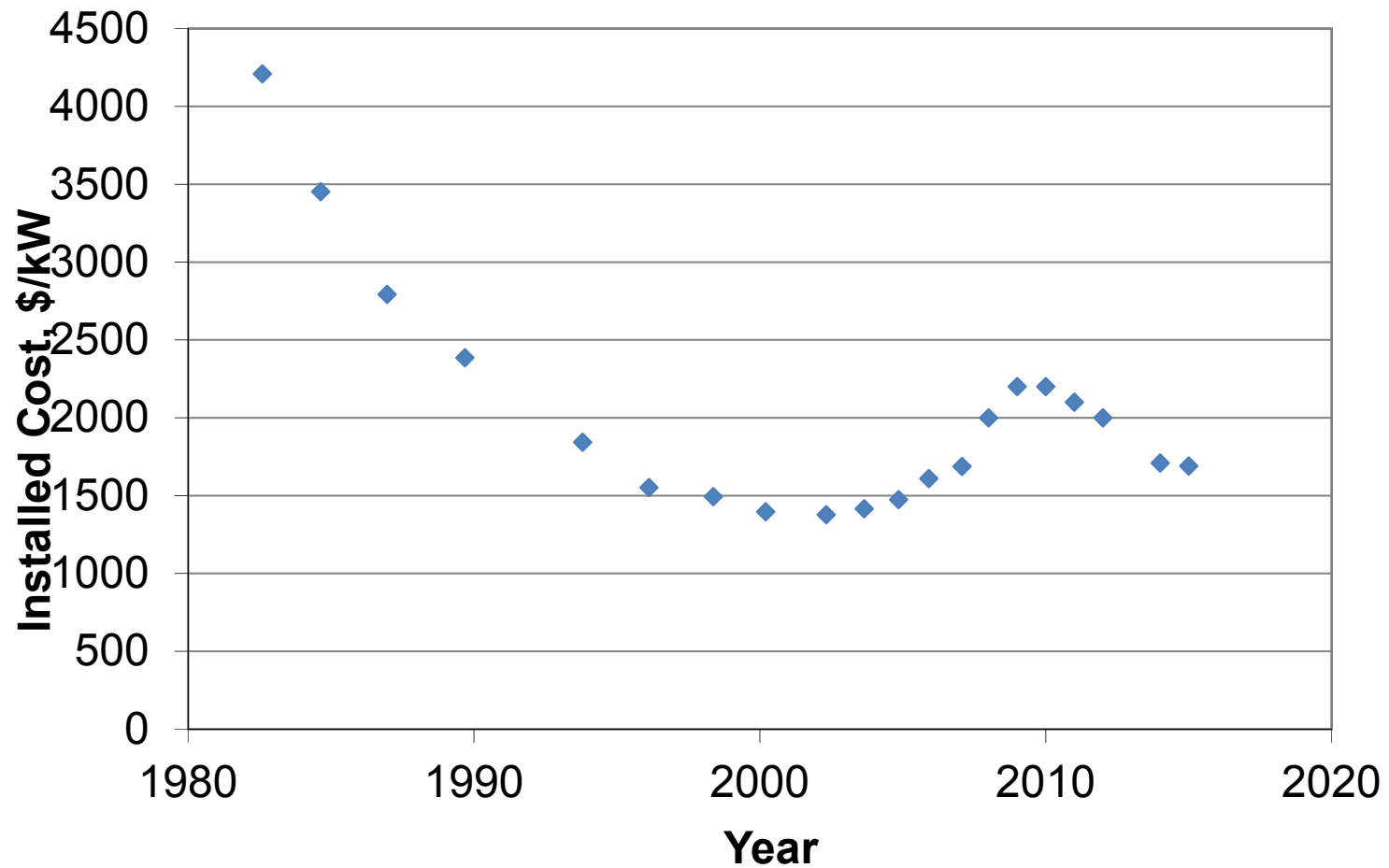
- pollev.com/purlwind



“Technology does not develop by itself”

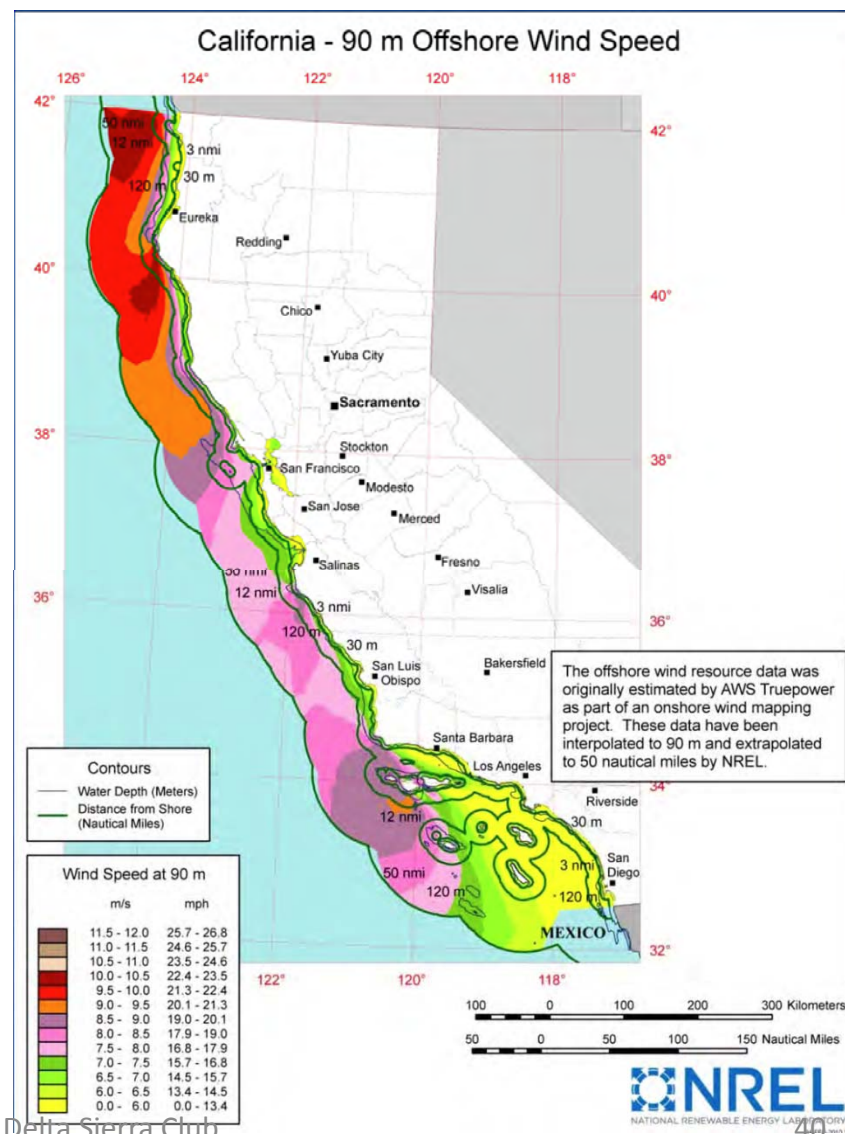
THE FUTURE

Cost Trends

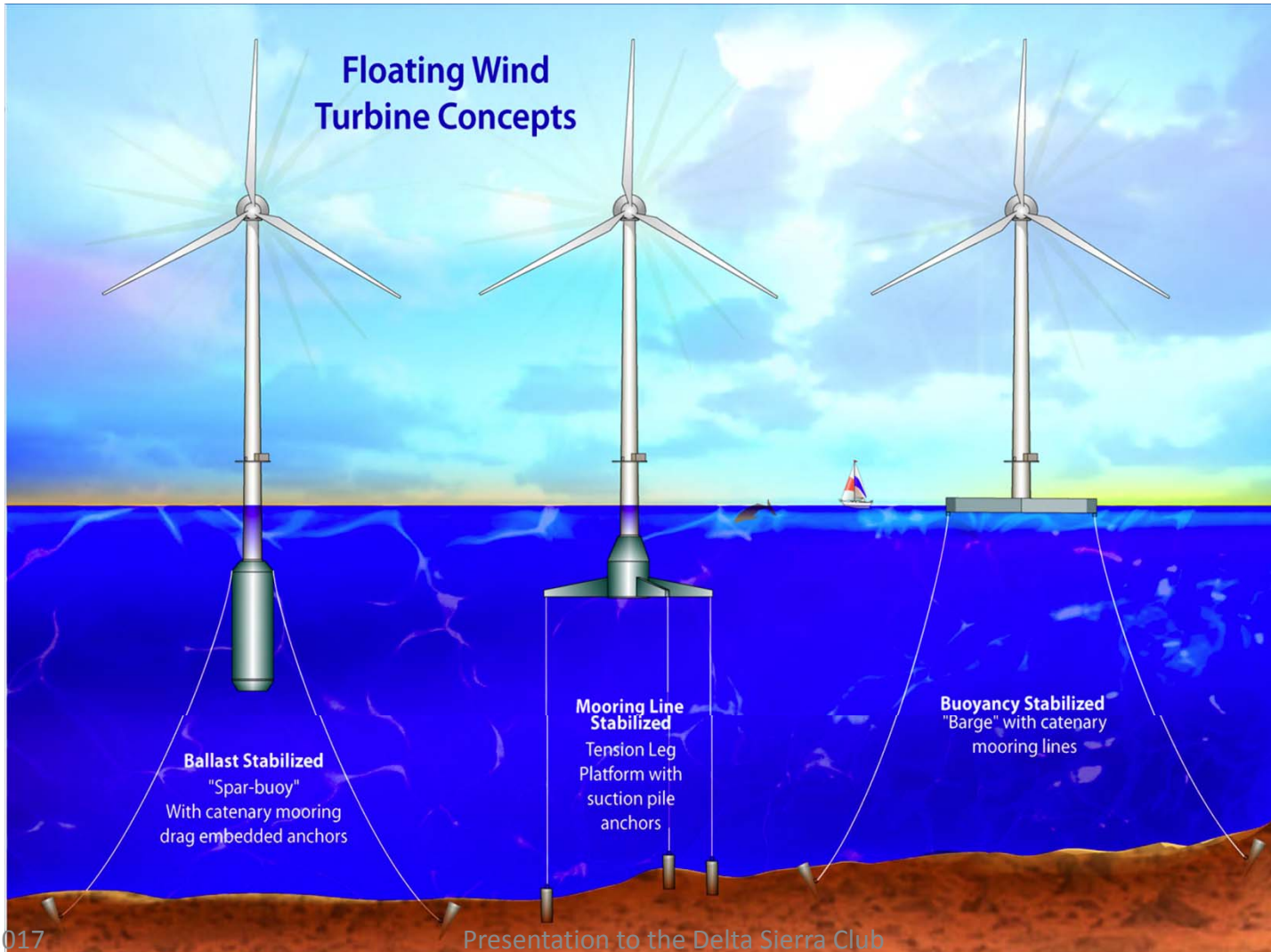


The California Offshore Resource

- Potential resources (Dvorak 2009)
 - Shallow water ~2 GW
 - Transitional water ~8 GW
 - Deepwater ~65 GW (compare 70 GW CA capacity)
- Offshore wind in California will most likely have to be deepwater
- Best resource in North Coast



Deepwater Technology



Will California go offshore?



- In the state of Maine:
 - 2010 State Legislation stating goals for 300 MW offshore power by 2020, 5000 MW by 2030
 - RFP for 30 MW floating demonstration project (Statoil responded)
 - University of Maine DeepCWind Consortium
- In the Golden State
 - Was the spark for the wind energy boom in the 1980s
 - No legislation, no funding, no commitment to offshore wind

Progress on Environmental Impacts

- Eagles/Bats/Grouse
- Detection, mitigation, deterrence
- E.g. radar detection



Golden Eagle at NWTC. Photo by John De La Rosa-Dennis Schroeder, NREL 35801

Integration with other renewables



- Storage needed for wind > 30% in CA
- Progress on storage
 - Electric vehicle fleet
 - Solar development in Southwest
- Diversity of resource big advantage

Back to the present



Swept blades- my dissertation topic



Closing Thoughts



- I am the fortunate son
- Wind turbines are more fun
- What to do with an aerospace degree

Questions?



- Thank you for inviting me.